Appendix N
Preliminary Setback Levee Erosion Protection Recommendations for Snohomish County Smith Island Estuary Restoration Project

October 10, 2013

Prepared for:
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Submitted to:
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October 10, 2013

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RE: SETBACK LEVEE EROSION PROTECTION RECOMMENDATIONS – SMITH ISLAND ESTUARY RESTORATION PROJECT, EVERETT, WASHINGTON

Dear Mr. Laird:

This preliminary letter report outlines design recommendations for scour and erosion protection to be placed on the marsh and waterward side of the Setback Levee for the Smith Island Estuary Restoration Project and accompanies the 60 percent design plans. The project location is shown in Figure 1.

EXECUTIVE SUMMARY

The Smith Island Estuary Restoration project involves setting back a 5,560-foot-long levee setback in order to restore approximately 375 acres of tidal marsh. The levee setback and restoration design includes erosion and scour protection measures. This letter report provides information regarding erosion and scour conditions for the proposed setback project. The levee setback itself is subject to different types of erosion, scour forces and scour depths, depending upon the levee proximity to Union Slough, Tidal Channel A and the open marsh areas. Significant erosion and scour resulting from both hydrodynamic, channel erosion and migration, and wind waves are anticipated at the north end of the project site near the confluence of Union Slough and Tidal Channel A. Southern sections of the setback levee are subject to wind waves and tidal channel development erosion and scour forces, for which reduced scour depths are anticipated and a modified erosion and scour protection design is recommended.

In addition to the levee setback, the project area has a natural gas pipeline running across the southern portion of the site. The pipeline is buried at a relatively shallow depth, as little as 4 feet below grade, and will require erosion and scour protection measures. This letter report recommends placing fill, grading, and seeding above the existing pipeline to promote drainage away from the pipeline; provides maintenance access; and recommends considering the additional use of buried windrows to protect the pipeline considering the elevated risks involved with protecting the structure.

SITE EROSION AND SCOUR FORCES

Scour protection measures are necessary to maintain a stable geometry for the levee. If excessive scour occurs, erosion of the toe can create oversteepened banks and lead to levee instabilities. The general practice is to provide scour protection equivalent to the level of protection design for the levee embankment overtopping and geotechnical conditions.

The proposed Setback Levee will be exposed to wave action and to river and tidal erosion and scour forces. The north end of the levee will be exposed to both types of forces, while the south end of the levee will likely be exposed primarily to wave action only, unless unanticipated channel migration of Union Slough or Tidal Channel A occurs. Figure 2 shows the zones where different scour and erosion processes will occur, and our recommendations for protection measures. The zones are delineated as follows:

- Zone A (Levee Setback Station [Sta.] 60+00 to 66+60) – Primarily tidal/river forces from Union Slough and Tidal Channel A with some wind wave and boat wave forces
- Zone B (Levee Setback Sta. 48+00 to 60+00) – Primarily tidal/river forces from Tidal Channel A with some wind wave forces
- Zone C (Levee Setback Sta. 10+00 to 60+00) – Primarily wind wave forces
- Zone D – Puget Sound Energy (PSE) natural gas pipeline – Primarily tidal channel formation and elongation potential and Union Slough channel migration potential

Our analyses did not consider overtopping erosion forces on the landward side of the levee. The Setback Levee design crest elevation is 15 feet (NAVD88) to match the 1 percent annual exceedance (100-year) flood event (Snohomish County, Wash., 2011). Flood flows exceeding the 1 percent annual exceedance event and overtopping the levee are beyond the design criteria for the Setback Levee. The Smith Island setback levee planned crest elevation is higher than most levees in the Snohomish River Delta and would be one of the last to overtop during a larger flood event.

WAVE EROSION AND SCOUR

Wave action is expected occur along the entire length of the Setback Levee, as shown in Figure 2. Wind waves will occur along the entire levee, while boat wake waves are anticipated to occur near the northern end of the levee where Buse Timber operates tugs and log rafts. We analyzed wind waves and boat wake waves to develop a design wave height and recommended riprap size.

Wind Wave Height Evaluation

The design wave height was calculated using methods outlined in the National Engineering Handbook, Section 16 – Drainage of Agricultural Lands, Chapter 6 – Dikes (NEH-16-6) (U.S. Soil Conservation Service, 1971). Wave height is a function of the fetch, design wind speed, wave runup, and other lesser factors. Wave heights were verified by using the simplified method for wave height calculations outlined in the Coastal Engineering Manual (U.S. Army Corps of Engineers [USACE], 2006).

We obtained hourly wind speed and direction measurements for the Snohomish County Airport (approximately 9 miles southwest of the site) for the period 1999-2011 (Weathersource, 2013). The wind data was imported into WRPlot 7.0 (Lakes Environmental Software, 2011) and analyzed to evaluate the prevailing wind direction, which is from the north, as shown in Figure 3. The prevailing wind direction was confirmed by records from the Western Regional Climate Center (WRCC, 2013). While the prevailing wind direction is from the north, peak wind speeds occur from the south.

Based on the 100-year floodplain extents (Federal Emergency Management Agency [FEMA], 2005), the open water fetch from the north is approximately 2.6 miles. If the presence of the existing dike on the north side of Union Slough is considered as a structure that can reduce and diminish wind waves, the open water fetch from the north may be reduced to less than 1 mile. The open water fetch from the south is approximately 2.3 miles from State Route 2, with several levee systems that could diminish fetch to less than 1 mile.

The NEH-16-6 contains a graph showing the relationship between design wind speed and design wave height based on open water fetch. Figure 4 has been provided at the end of the report showing this reference. The design wind speed is chosen based on the class of the dike, which ranges from Class I to Class III. Because the proposed Setback Levee will be close to Interstate 5 (I-5) and adjacent farm properties, and the potential for damages if the levee is compromised, Class I was selected as the design standard. Class I dikes use a design wind speed of 100 miles per hour. For a fetch of 2.6 miles, the estimated wave height is 4 feet. For a fetch of 1 mile or less, the estimated wave height is 3.2 feet.

Using the USACE Coastal Engineering manual (USACE, 2006), wave heights were verified based on the design variables listed above; the design significant wave height was calculated to be 4 feet. According to the USACE manual, the significant wave height is limited to 0.8 times the depth of water in which the waves form. Therefore, in areas where the depth of water is less than 5 feet, the significant wave height could be reduced.

Wave runup in NEH-16-6 is equal to 1.5 times the design wave height, measured from the still water surface. Therefore, the design wave runup height is 6 or 4.8 feet, for a fetch of 2.6 or 1 miles, respectively.

The effect of flood, wind wave, and storm surge wave overtopping of the levee is beyond the scope of this report, was not explicitly evaluated for the design, and is not required by Snohomish County or Dike District No. 5. A brief discussion of overtopping follows.

The 10-year (10 percent annual exceedence probability) water surface elevation varies from 12.0 feet NAVD 88 at 12th Street to 11.5 feet NAVD 88 at I-5 (ESA Adolfson, 2007). The 100-year (1 percent annual exceedence probability) water surface elevation is 15 feet NAVD 88. The design height of the levee is 15 feet NAVD 88, so wind waves in combination flood conditions could overtop the levee. The likelihood of this cumulative annual exceedance probability, or probability of exceedance during the expected life of the project has not been evaluated.

Mr. Roy Harris has been involved with the Smith Island project and helped establish the levee design elevations at 15 feet NAVD 88. His observations of historical flooding in the Snohomish River delta are that floods and wind waves do occur simultaneously, but that the overtopping of waves does not result in significant depths of water overtopping the levee, nor significant levee erosion (Harris, 2013).

Boat Wave Height Analysis

Boat wave heights were analyzed using an equation developed by Bhowmik and others (1991), and is calculated as a function of the speed, length, and draft of the boat, and the distance from the boat to the shore. Boat traffic along Union Slough is expected to consist primarily of work tugs towing timber rafts to Buse Timber. Limited data is available for boat parameters; however, assuming a work tug 45 feet in length, with a draft of 6 feet, traveling at 2 knots and 20 feet from the shore, the calculated maximum wave height is 5 feet. It should be noted that the Bhowmik equation was developed using data from recreational boat traffic, and correlates increasing wave height with decreasing speed in a manner that is likely overly conservative for the site conditions. Based on information provided by Snohomish County (Aldrich, 2013), it appears that the wave height created by tug boats towing timber rafts is less than the predicted wind wave heights. Therefore, wind wave heights dictate the design, and not boat wave heights. Also, wind wave heights and boat wave heights would not likely occur simultaneously and are, therefore, not combined or additive for estimating design height.

Rock Size for Wave Action Forces

Rock was sized for wave action based on the relationship developed by Douglass and Krolak (2008). Rock size is a function of wave height, levee side slope, and the specific gravity of the rock and water. Slopes were assumed to be 3:1 based on the preliminary levee design (Shannon & Wilson, Inc. (S&W), 2013); specific gravities of 2.65 and 1.03 were used for rock and saltwater, respectively.

For a design wave height of 6 feet, the median rock weight (W_{50}) calculated is 1,270 pounds (lbs), which corresponds to a median particle size (D_{50}) of 2.1 feet. For a design wave height of 4.8 feet, the values are 650 lbs and 1.7 feet, respectively. A D_{50} of approximately 2 feet is recommended with a minimum thickness of 3 feet.

We recommend using Class B riprap based on Washington State Department of Transportation (WSDOT) Standard Specifications, Section 9-13, Rock for Erosion and Scour Protection (WSDOT, 2012).

TIDAL AND RIVER EROSION AND SCOUR ANALYSIS

Hydraulic Modeling

The hydraulic parameters used in the tidal and river erosion and scour analysis are based on the results of hydraulic modeling performed by others. Those sources include:

- Tetra Tech RiverFLO-2D model (Tetra Tech, 2012).
  - Two-dimensional hydraulic model
  - Post-implementation conditions for Smith Island Restoration Project
  - 15-year storm design event (December 2009)

- GeoEngineers/WEST HEC-RAS Model (GeoEngineers/WEST, 2011)
  - One-dimensional, unsteady state hydraulic model
  - Post-implementation conditions for Smith Island Restoration Project
  - 2009 Water Year

- Battelle Hydrodynamic Model (Yang and Khangaonkar, 2007)
  - Station SU-1

Model results from the HEC-RAS model generally indicate similar velocities to the RiverFLO-2D model. The HEC-RAS model results were used in this analysis. Snohomish County has selected the December 2009 event (approximately 15-year return interval) as the design event. Areas behind the levee are mapped as 100-year floodplain, so design for a 100-year event is not required.

Scour Depth

Following levee removal, tidal and river scour forces are expected to occur along the Setback Levee, as shown in Figure 2 and as summarized below:

- Zone A
  - Long-term degradation
  - Contraction scour (scour due to abrupt changes in channel and floodplain width)
  - Abutment scour (scour due to an obstruction placed in the waterway)

- Zone B
  - Long-term degradation
  - Bend scour (scour at the outside of a bend due to potential tidal channel migration)

   - Floodwall scour (scour along a hardened feature due to potential tidal channel migration)

- Zone C
   - Scour is not anticipated

Long-term degradation was not analyzed for the purposes of this design, as it depends on basin-wide geomorphic and sediment transport factors that are beyond the scope of this analysis.

Zone A Scour

Scour in Zone A is expected to consist primarily of contraction scour and abutment scour from Union Slough. This zone will have higher velocities as river and tidal flood flows converge at the north corner of the proposed Setback Levee. Input variables for contraction and abutment scour were obtained from the WEST HEC-RAS model (GeoEngineers/WEST, 2011). Contraction scour was evaluated using methods outlined in HEC-18 (Arneson and others, 2012). Based on a comparison between the velocity in Union Slough and the critical particle velocity for the median bed particle size, the sediment transport mode appears to be live bed scour. For live bed scour conditions, there is no scour calculated during the modeled event.

Abutment scour was evaluated using methods outlined in HEC-18 (Arneson and others, 2012). Abutment scour is a function of hydraulic parameters intended to model the amount of flow blocked by an abutment. In this case, the position and location of the levee setback acts similarly to a bridge abutment contracting the floodplain flow width. Based on the Richardson and Froehlich equations, abutment scour of 39 to 41 feet below existing channel bottom was calculated for the design event.

The above equations generally over predict scour depths (Arneson and others, 2012), due to discrepancies between laboratory and field conditions. The primary discrepancy relates to the difficulty in determining the length of abutment assumed to be blocking the flow. A sensitivity analysis was performed by varying the length of abutment in the Froehlich equation from 0 to 500 feet, which produced calculated scour depths ranging from 14 to 55 feet, respectively.

Another factor to consider is that the existing I-5 bridge, downstream of Zone A, has created a bed equilibrium that will likely not be significantly changed due to the proposed levee setback along Zone A (Snohomish County, Wash., 2011). It is, therefore, reasonable to assume that the depth of scour along the Setback Levee in Zone A will be limited to the existing bed elevations observed in Union Slough through the I-5 bridge. The existing bed elevation in Union Slough between I-5 and the Setback Levee varies from -6.5 to -20 feet (NAVD88), based on cross-sections in the HEC-RAS model and bathymetric survey of the area (GeoEngineers/WEST, 2011) and bathymetric survey data provided by Snohomish County in 2013. These elevations correlate to the lower end of the scour depth prediction of 14 feet discussed in the previous paragraph. Considering the anticipated limiting and controlling bed elevation of Union Slough, we recommend that scour countermeasures along the Setback Levee be designed to a general bed elevation -10 feet (NAVD 88), and localized scour bed elevation of -20 feet (NAVD88) near the northernmost section of the setback levee , with additional volume of riprap placed in launching trenches to fill in the anticipated scour areas.

Scour due to tidal forces at the toe on the waterward side of the levee is expected to be less than wind/boat waves and riverine forces. The Skagit Bay Hydrodyamic Model (Yang and Khangaonkar, 2007) indicates that the velocities due to tidal exchange in Union Slough are generally less than 0.2 meter per second (0.7 foot per second [ft/s]), which is less than velocities expected due to flooding (Tetra Tech, 2012). Therefore, tidal scour was not explicitly evaluated.

The recommended scour protection measures along Zone A are to protect the levee from future abutment scour at the mouth of Tidal Channel A meander. Riprap for scour protection should be placed as a wedge of material at the levee toe that can launch to down to an elevation of -10 feet (NAVD88).

Zone B Scour

Scour forces in Zone B are expected to consist primarily of tidal channel meander bend scour and possible increased bend scour along the hardened bank protection area near Tidal Channel A. If Tidal Channel A adjusts and meanders, it could migrate towards the Setback Levee toe. Tidal Channel A is currently approximately 150 feet from the toe of the proposed Setback Levee near Sta. 52+00 and 50 feet from the toe at Sta. 65+00. Previous studies by WEST Consultants (WEST) and GeoEngineers (WEST, 2007 and GeoEngineers/WEST, 2011) did not indicate that significant channel migration or avulsion would occur.

Bend scour was evaluated using equations developed by Simons, Li and Associates Inc. (SLA, 1985), Maynord (1996), and NRCS (2007). Bend scour is a function of channel radius of curvature, width and depth (all equations) and velocity and slope (Zeller equation only). Radius of curvature and width were estimated using aerial photographs. Other variables were taken from the GeoEngineers/WEST HEC-RAS model. Floodwall scour was evaluated using an equation developed for sand bed channels (Mussetter and others, 1994), and is a function of depth, angle of attack, and Froude number. The sand bed channel is likely conservative considering the existing soils and sediment profiles are primarily silty and slightly clayey silts occurring as estuarine deposits, which have higher cohesion and are less erosive than non-cohesive sands. Depth and Froude number were obtained from the GeoEngineers/WEST HEC-RAS model, while angle of attack was estimated using aerial photographs. The estimated bend and floodwall scour depths range from 2 to 25 feet below the existing Tidal Channel A thalweg. Tidal Channel A is not expected to scour below the Union Slough elevation, so a design scour elevation of -10 feet is recommended to match the Union Slough scour elevation. This roughly equates to the average of the bend and floodwall scour equations.

The recommended scour protection measures along Zone B are to protect the Setback Levee from future Tidal Channel A meander. Riprap for scour protection should be placed as a wedge of material at the levee toe that can launch to down to an elevation of -10 feet (NAVD88). This is approach is conservative for current conditions because Tidal Channel A is a fair distance from the proposed setback levee in most areas. However, the cost would be greater, and constructing a launchable riprap wedge more difficult, if deferred until channel migration occurs and ends up near the levee. Therefore, we recommend constructing the levee slope and launchable riprap wedge shown in Figure 5.

Rock Sizing Tidal and River Erosion and Scour

Revetment rock sizes were calculated using equations from NRCS (2007). The Maynord equation is dependent on channel curvature, depth, velocity, and riprap slope and thickness. The USCAE recommends the Maynord equation for sizing riprap erosion protection. The Isbash equation is simplified, depending primarily on velocity; therefore, we used it as a check on the rock size calculated by the Maynord equation. Rock sizes were calculated separately for Zones A and B.

Zone A Rock Size

Based on the Maynord equation, the calculated median rock size (D_{50}) is 0.5 foot. The calculated median rock size by the Isbash method is 0.5 foot. Note that both values are significantly smaller than those calculated to resist wave action forces, so the rock size for wave action forces controls the design and should be used in Zone A (D_{50} = 2 feet). Rock size could vary vertically along the waterward slope depending on the potential for wind wave or tidal/river erosion forces.

Zone B Rock Size

The Maynord and the Isbash equations result in a rock size that is negligible in Zone B. This is likely due to the relatively slow velocities in the channel and the 3:1 side slopes of the Setback Levee. Therefore, the rock size in Zone B should be based on the rock size for wind wave forces (D_{50} = 2 feet). Rock size could vary vertically along the waterward slope depending on the potential for wind wave or tidal/river erosion forces.

Zone C Rock Size

Zone C is not subjected to river or tidal erosion and scour, so the rock size in Zone C should be based on the rock size for wind wave forces (D_{50} = 2 feet).

WOOD IMPACTS

There is a potential for large wood transported by the Union Slough into the marsh restoration area, as well as for large wood derived from existing forested areas to be exported from the project site. FEMA (2011) has developed a method estimating debris impacts to structures in the floodway. Using the FEMA method, and assumptions regarding size of wood and impact speeds, an estimate of riprap size to resist wood impacts was calculated at a median diameter of 2.6 feet, which is slightly higher than the wind wave results. Wood debris impacts would likely be localized, and in many cases the velocities at impact will be minimal. The depths required for large wood debris to float will occur at or near high tide when velocities in the marsh areas are minimal. Wood debris transport will then be from wind and wave transport rather than hydrodynamic velocities. Therefore, we consider the estimate provided using the FEMA method to be conservative and recommend a reduced wood impact erosion protection rock size of (D_{50} = 2 feet).

PUGET SOUND ENERGY (PSE) PIPELINE SCOUR

An existing 16-inch PSE natural gas pipeline is near the south end of the Setback Levee, shown as Zone D in Figure 2. The pipeline invert is approximately 4 feet below the surface through most of the marsh (WEST, 2007). The pipeline is susceptible to scour due to formation and elongation of new tidal channels (and existing drainage ditches) along the marsh near the pipeline and Union Slough scour and migration.

Union Slough Scour

WEST performed a channel migration and scour evaluation of the pipeline (WEST, 2007). The report evaluates the effect of removing the existing levee on the pipeline. The report states:

> "In summary, the risk of channel migration affecting the pipeline alignment between Union Slough and I-5 if existing levees are breached is considered to be low. The risk is minimized by the proposed locations of levee breaching and the existing infrastructure that control the potential location and magnitude of flow along the left overbank of Union Slough Additionally, as previously described, the general risk of dynamic channel migration is low due to the general geomorphic setting of the project. It is noted that some risk will exist once the levees are breached and maintenance of the levees left in place ceases. However, during the design life of the pipeline, the risk due to channel migration is considered to be low."

Based on the WEST assessment, protection of the pipeline from Union Slough scour and channel migration is not necessary. The WEST report does not consider pipeline protection for interior marsh areas.

Tidal Channel Development

The formation of new tidal channels and elongation of new and existing tidal channels (or existing drainage channels) to the south could impact the PSE Natural Gas pipeline, shown as Zone D in Figure 2. Recently, in October 2013, Northwest Hydraulic Consultants (NHC) completed multidimensional, low flow tidal modeling of the setback site to evaluate a low flow channel from the City of Everett marsh flowing east and north towards the Smith Island east breach. The modeling results indicate that a channel of this type could scour and impact the pipeline, and that localized marsh drainage has the potential to erode tidal channels near the pipeline.

We performed estimates of tidal channel development, to estimate potential scour depths, prior to the NHC low flow tidal modeling using methods described by Hood (2007) to evaluate tidal channel formation. The island areas that could form a tidal channel impacting the pipeline is approximately 18 acres in area (shown as Lobe 1A in Figure 6). Using Hood's equations, we predict approximately 6 to 7 tidal channels could form in the island area, and the largest tidal channel top width would be on the order of 16 feet. Given side slopes of 1.5 Horizontal to 1 Vertical, the depth of the tidal channel could be up to 5 feet. Other areas in the tidal marsh (shown as Lobes 1, 2, and 3 in Figure 6) could create outlet channels up to 37 feet wide, which would have a depth of up to 12 feet. There is a potential for tidal channel formation to affect the PSE pipeline. Several options are available for countermeasures, including:

- Option A – Place trenched riprap on both sides of pipeline to intercept tidal channel formation (also known as a "buried windrow").
- Option B – Place riprap immediately around pipeline to the anticipated scour depth.
- Option C – Perform grading and plant vegetation along the pipeline to raise the floodplain, which would reduce drainage area and volume, and redirect drainage flow away from the pipeline both to the north and south (some additional drainage towards the City of Everett marsh area could occur).
- Option D – Monitor tidal channel formation long-term and mobilize scour countermeasures if tidal channel formation is observed in the vicinity of the pipe.

The final pipeline erosion protection configuration should be developed through coordination with the County and PSE. Figure 8 shows conceptual cross sections of pipeline protection Options A through C.

Rock Size

Velocities and shear stresses are low near the PSE pipeline. According to the Tetra Tech model, velocity is expected to be 1 to 2 ft/s across the marsh plain. According to the Battelle hydrodynamic model, tidal channel velocities are expected to be about 0.7 ft/s. Rock sizes were calculated using equations from NRCS (2007), which resulted in a D_{50} of 0.04 foot. As a matter of practicality, and to account for shifting tidal channel patterns which may affect local velocities, we recommend using quarry spalls meeting WSDOT Standard Specifications, 9-13.6 Quarry Spalls.

FILTER ANALYSIS

Riprap installed over fine-grained soil can be susceptible to failure due to erosion of the underlying soil. To prevent failure, a granular or geotextile filter should be installed to retain the underlying soil in place. To evaluate whether or not a filter is required, the gradation of the underlying material is compared to the gradation of the riprap based on relationships outlined in HEC-11 (Brown and Clyde, 1989). The gradation of the underlying riprap material will be the proposed levee fill and native soils. The riprap gradation will be based on WSDOT standard specifications for Class B Rock for Permanent Erosion Control (WSDOT, 2012).

Based on the results of the calculations, the proposed levee fill will be susceptible to erosion if not protected by a filter. Preliminary calculations indicate that for a granular filter to be used, at least two layers will be required. Given the magnitude of the riprap placement and associated cost of a granular filter, a geotextile filter is likely to be more cost effective.

The geotextile filter design is based on the WSDOT Design Manual for Geosynthetics (WSDOT, 2009). Specifications for geotextile are contained in the WSDOT Standard Specifications, Sections 9-33.1 and 9-33.2. The specifications for Geotextile for Permanent Erosion Control should be used for the filter. Given that the levee fill will have 20 to 35 percent passing the No. 2 00 sieve, Class B geotextile should be used. If moderate survivability geotextile is used, a 12-inch aggregate cushion is needed between the fabric and the riprap. High survivability fabric may be used without a cushion if care is taken during riprap placement.

We recommend that the riprap be placed on the geotextile fabric in lifts beginning at the lowest elevation. Riprap lifts should be carefully placed on the geotextile; end dumping riprap onto the geotextile should not be allowed. The maximum drop height of the riprap onto the fabric should not exceed the manufacturer's recommendation or 1 foot, whichever is less. If any portion of the geotextile is damaged during installation, it should be promptly replaced or repaired in conformance with the manufacturer's recommendations.

SUMMARY OF FINDINGS

Based on the results of the above analyses, our findings are summarized as follows:

- Portions of the Setback Levee in Zones A and B will be exposed to forces from wave action, tidal and river erosion, and scour forces.

- The recommended wind wave design wave height is 4.8 feet along the entire Setback Levee, considering the various levees, roads, forested areas and terrain features that will limit fetch lengths and reduce wave heights across the Snohomish River delta.
- The minimum median rock size to resist the wave design height forces is 2 feet. Rock size could vary vertically along the waterward slope depending on the potential for wind wave tidal/river erosion forces.
- Wave and flood overtopping of the Setback Levee is not considered in the design.
- Scour is likely to occur along the north end of the Setback Levee due to contraction of flood flows in Zone A and potential channel migration in Zone B. Scour depths are likely to be controlled by the elevation of Union Slough near an elevation of -10 to -13 feet NAVD 88. A value of -10 was selected for design.
- The WEST report indicates scour and channel migration protection of the pipeline from Union Slough is not necessary.
- Tidal channels could form and erode towards and into the PSE pipeline area if appropriate protection measures are not included in the design.
- Wave action and large wood debris impact forces control rock size in Zones A through C.

RECOMMENDATIONS

Zones A and B

The typical design section for Zones A and B is shown in Figure 6. We recommend using riprap sized based on the wave action forces (WSDOT Rock for Erosion and Scour Protection, Standard Specification Section 9-13.4, Class B). The riprap should be at least 3 feet thick. Some scour is expected in Zone A, so Figure 6 shows additional rock placed along the levee toe to launch in the event of scour. We recommend the use of a geotextile filter fabric under the riprap. Topsoil material may be placed over the riprap, as shown in Figure 6. The volume of rock placed should be commensurate with the anticipated scour depths using a launchable rock toe that will vary along Zone A and B. The volume of rock will be further developed in the final design phase of the project.

Zone C

The typical design section for Zone C is shown in Figure 7. We recommend using riprap-sized based on the wave action forces (WSDOT Rock for Erosion and Scour Protection, Standard Specification Section 9-13.4, Class B). The riprap should be at least 3 feet thick. Minimal scour is expected in Zone C, so Figure 7 shows the rock keyed in approximately 3 feet below the surface. We recommend the use of a geotextile filter fabric under the riprap, as outlined above. Topsoil material may be placed over the riprap, as shown in Figure 7. Tidal channel formation and migration should be monitored, and additional rock protection installed if necessary to prevent impacts to the Setback Levee.

Zone D

Three options for the design section for Zone D are shown in Figure 8. The original recommendation for pipeline protection and preferred method was use of Option C – Filling, Grading and Planting a berm over the pipeline. However, recent low flow hydrodynamic modeling indicates that tidal channels could encroach upon the pipeline. Considering the risks associated with the damaging the pipeline, which could include rupture of the pipe causing possible public safety and environmental impacts due to pipeline leakage, we recommend more robust protection measures. Our recommendation includes using a possible combination of Options A and C raising areas above the pipeline using fill, grading and seeding methods combined with windrow erosion protection at the toe of the fill and grading areas on both sides of the pipeline, pending design coordination with PSE, and the City of Everett who is working on other fill grading options associated with 12th St. NE near the pipeline. Our rationale for recommending this combined protection method is that risks associated with this structure are high, and therefore a more conservative approach is recommended, especially in light of additional hydrodynamic modeling information provided by the County.

LIMITATIONS

This letter report was prepared for the exclusive use of Otak and Snohomish County and other members of the design team for specific application to the design of the Smith Island Estuary Restoration Project as it relates to the erosion control aspects discussed in this letter report. The data contained in this letter report are based upon site conditions as they existed at the time this letter report was prepared, and upon hydraulic modeling results and reports, scour and channel migration analyses prepared by others. Within the limitations of the scope, schedule, and budget, the data presented in this letter report were collected and presented in accordance with generally accepted professional engineering practice in this area at the time this letter report was prepared. No warranty, express or implied, is made.

The scour and erosion types evaluated in this letter report were limited to those described in this letter report. Other long-term geomorphic changes at the site could influence scour and erosion patterns, but were not evaluated. Those patterns include long-term sedimentation and degradation, mainstem channel migration and avulsion, dredging and filling of the channels by others, placement of large woody debris or other habitat features, and changes in land use at or upstream of the site, and overtopping of the levee setback.

We assume that the data and modeling output provided by others has been accurately developed calibrated and that it comprises reliable information to perform the analysis. S&W cannot make claims regarding the correctness or accuracy of these models and data provided by others. Facts and conditions referenced in this letter report may change over time. Facts and conditions set forth here are applicable as described only at the time this letter report was written. We believe that the conclusions stated here are factual, but no guarantee is made or implied.

This letter report was prepared for the exclusive use of Otak and Snohomish County and its representatives and in no way guarantees that any agency or its staff will reach the same conclusions as S&W.

Sincerely,

SHANNON & WILSON, INC.

10/10/13

David R. Cline, P.E.
Senior Associate

ADH:DRC/adh

Enc: References (3 pages)
Figure 1 – Vicinity Map
Figure 2 – Erosion and Scour Protection Zones

Figure 3 – Wind Rose
Figure 4 – NEH 16-6 Wind Wave Design Heights
Figure 5 – Drainage Lobes
Figure 6 – Typical Levee Section Zones A and B
Figure 7 – Typical Levee Section Zone C
Figure 8 – Typical Pipeline Section Zone D

c: Bob Aldrich, Snohomish County

REFERENCES

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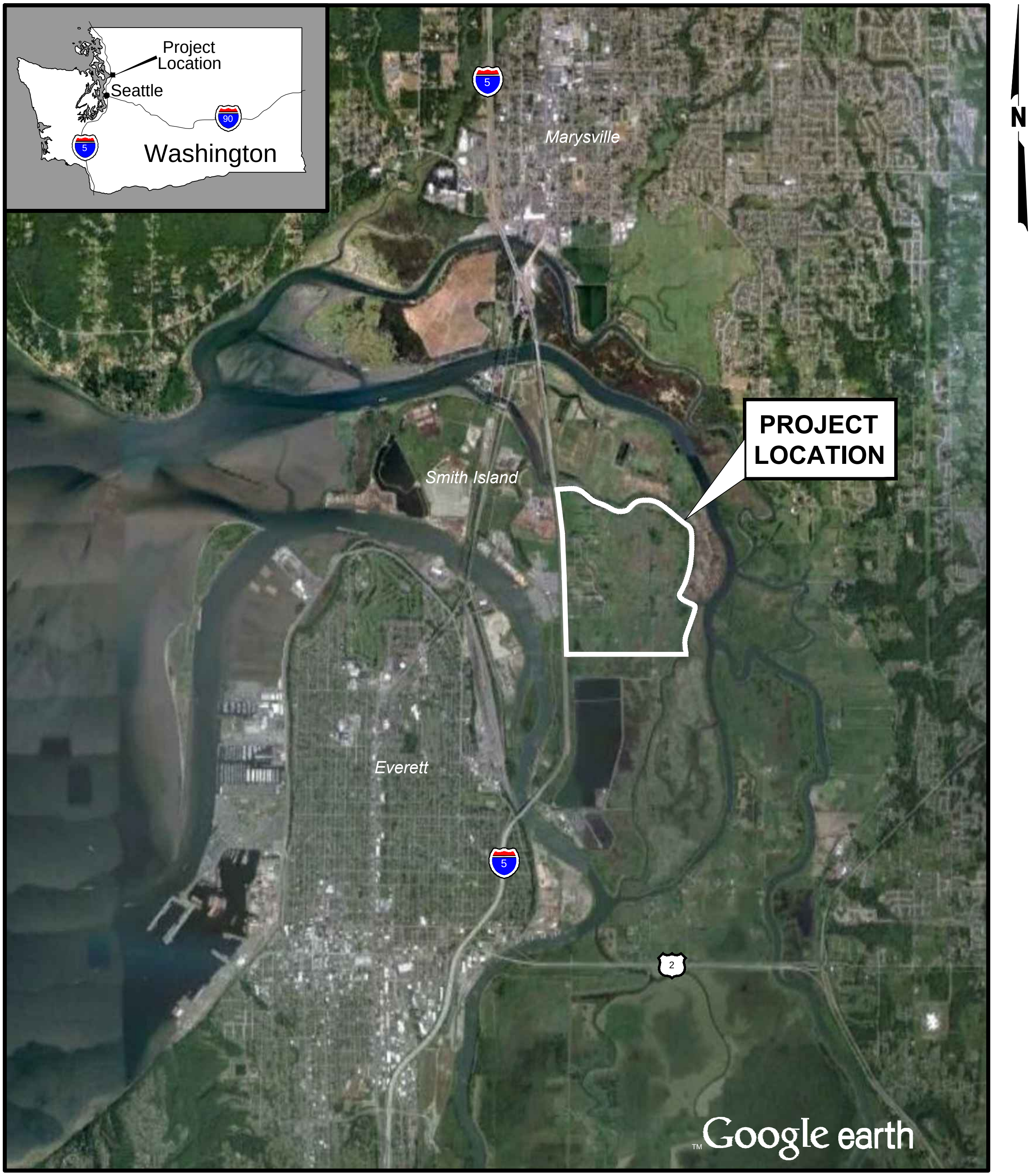

0 1 2

Scale in Miles

NOTE

Map adapted from aerial imagery provided by Google Earth Pro, reproduced by permission granted by Google Earth ™ Mapping Service.

Smith Island Estuary Restoration Project
Snohomish County, Washington

VICINITY MAP

October 2013 21-1-12405-060

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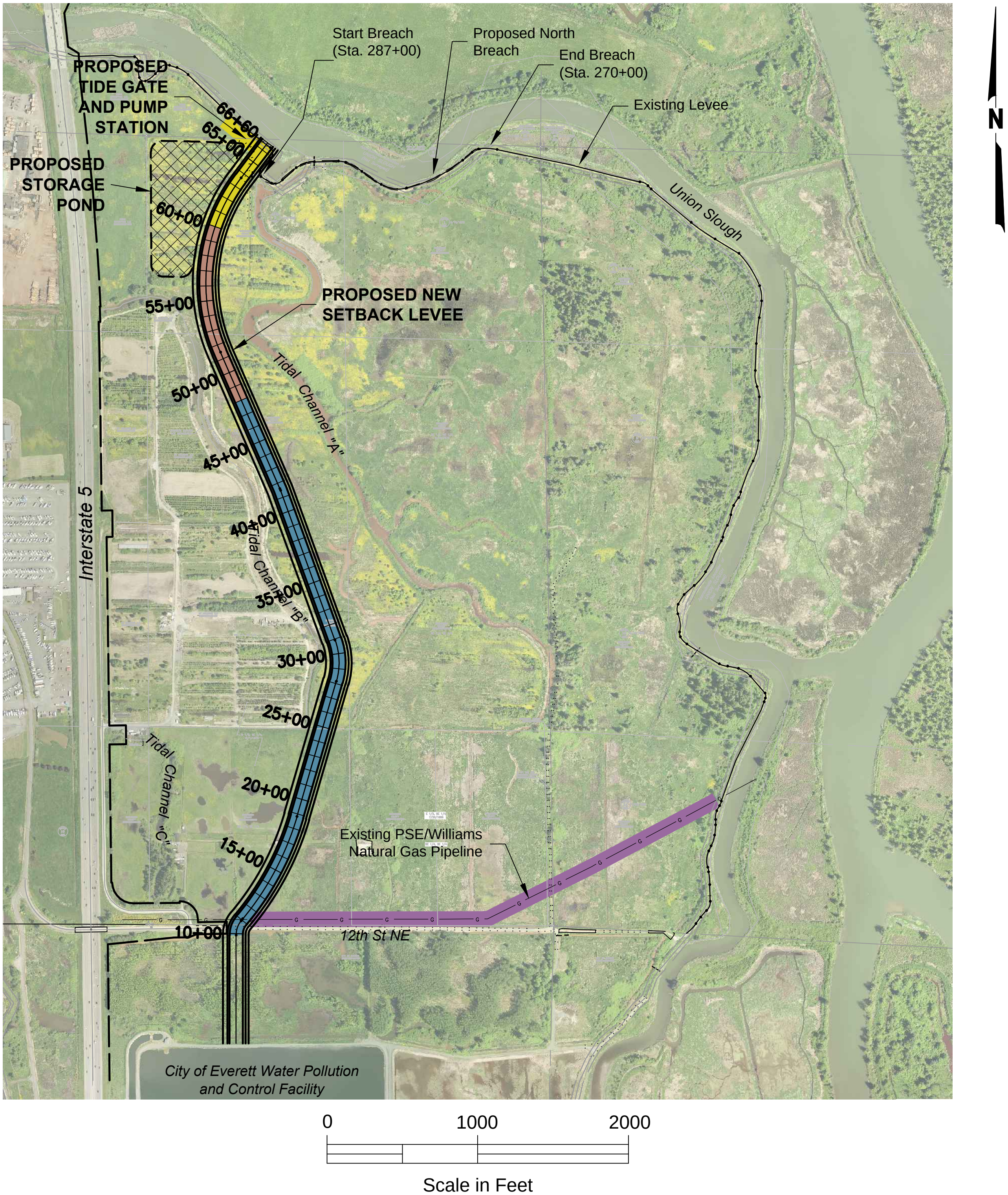
FIG. 1

Filename: I:\WIP\21-1\12405 Smith Island (Snohomish Cty)\CAD_FIGURES\-060\21-1-12405-060 Fig 1.dwg Date: 11-27-2013 Login: SAC



LEGEND

Zone A - River/Tidal/Boat and Wind Wave

Zone B - River/Tidal/Wind Wave

Zone C - Wind Wave

Zone D - Tidal Channel Development/Elongation

NOTE

Figure adapted from electronic files provided by Otak.

Smith Island Estuary Restoration Project
Snohomish County, Washington

EROSION AND SCOUR PROTECTION ZONES

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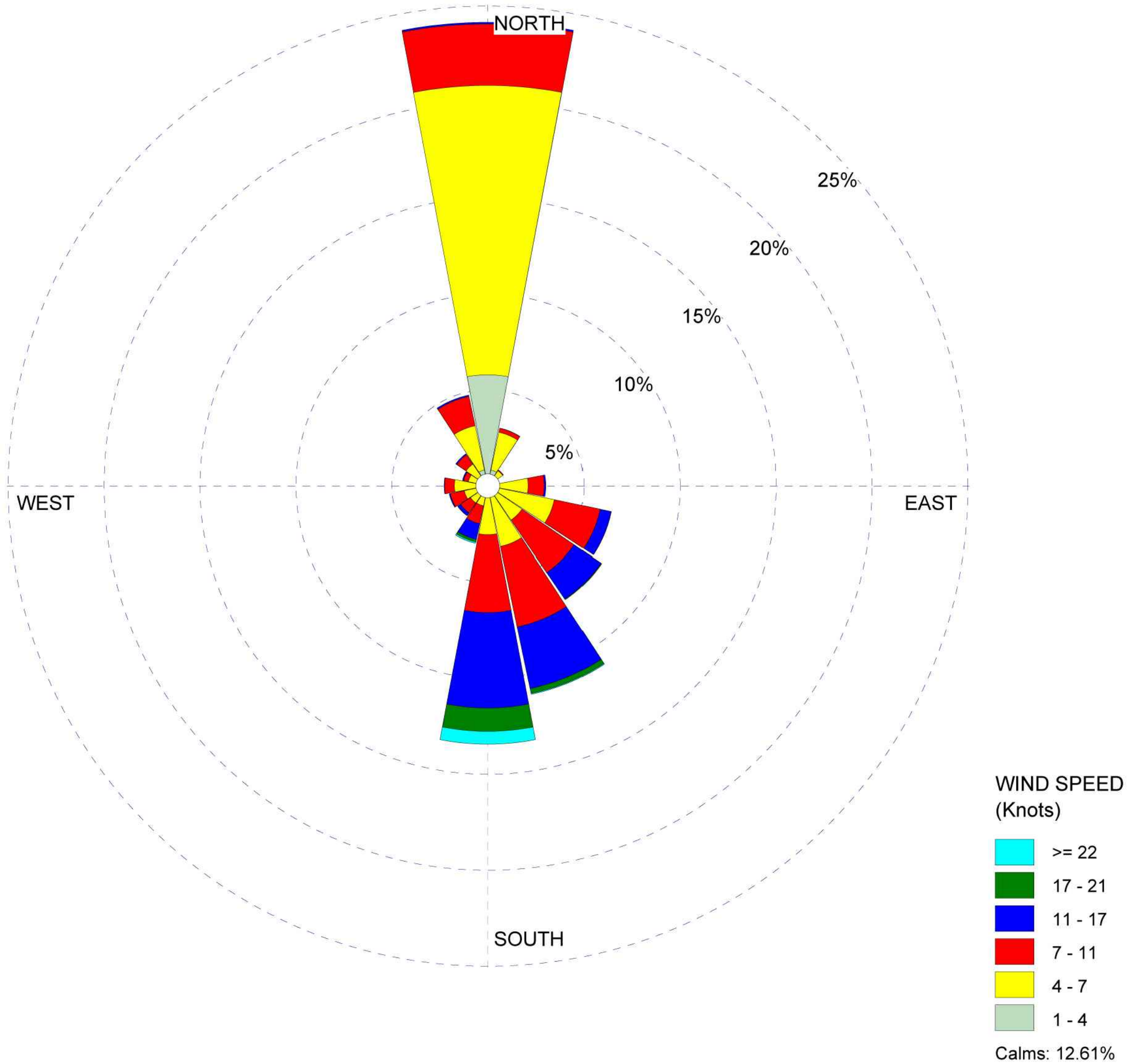
FIG. 2

Filename: I:\WIP\21-1\12405 Smith Island (Snohomish Cty)\CAD_FIGURES\-060\21-1-12405-060 Plans (Erosion Protection).dwg Date: 11-27-2013 Login: SAC

Filename: I:\WIP\21-1\12405 Smith Island (Snohomish Cty)\CAD_FIGURES\-060\21-1-12405-060 Fig 3 (Erosion Protection Letter).dwg Date: 11-27-2013 Login: SAC



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WIND ROSE

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FIG. 3

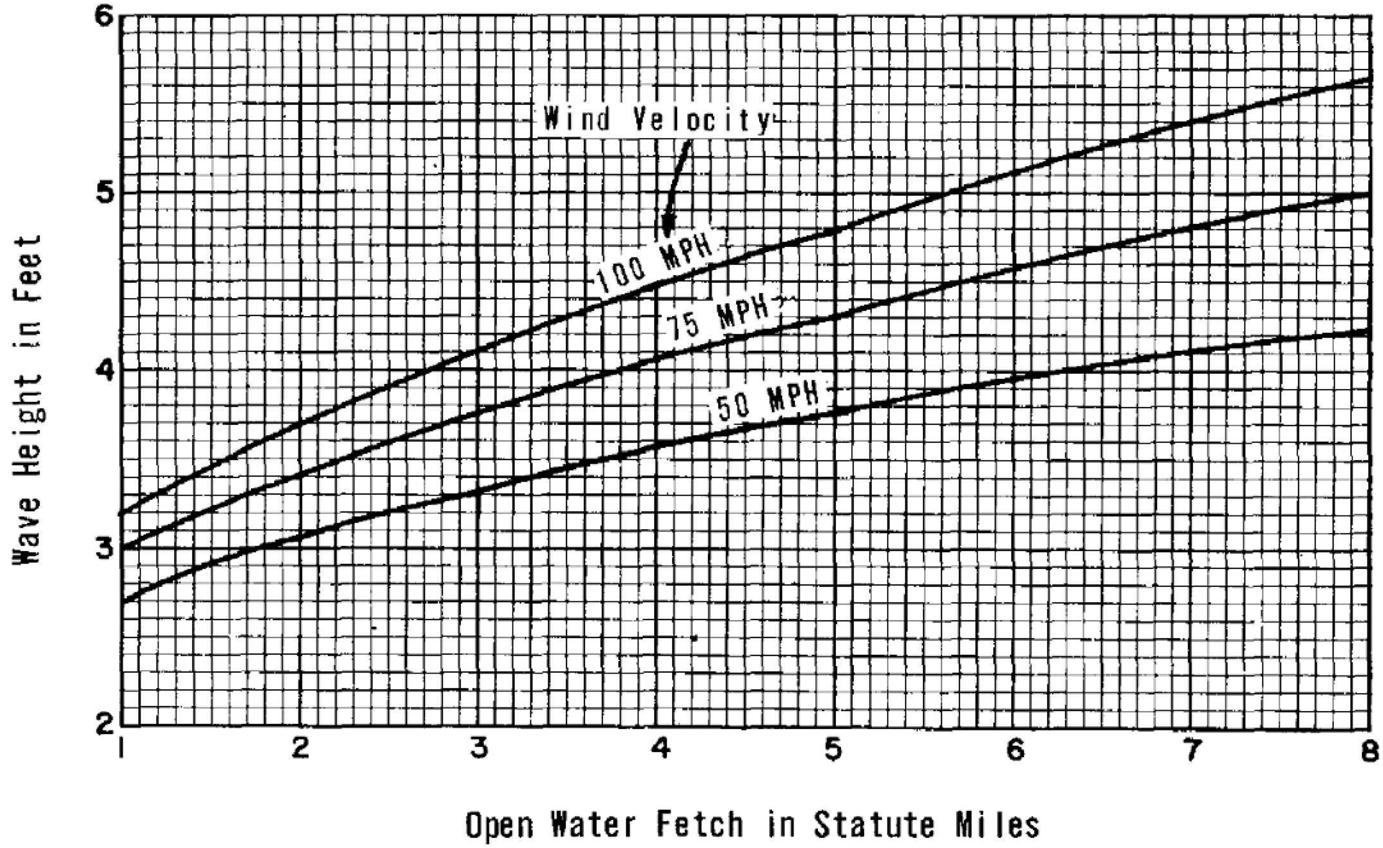

Figure 6-2, Wave height curves

Smith Island Estuary Restoration Project
Snohomish County, Washington

DESIGN REFERENCE
U.S. SOIL CONSERVATION SERVICE
WIND WAVE DESIGN HEIGHTS
(U.S. SCS - 1972)

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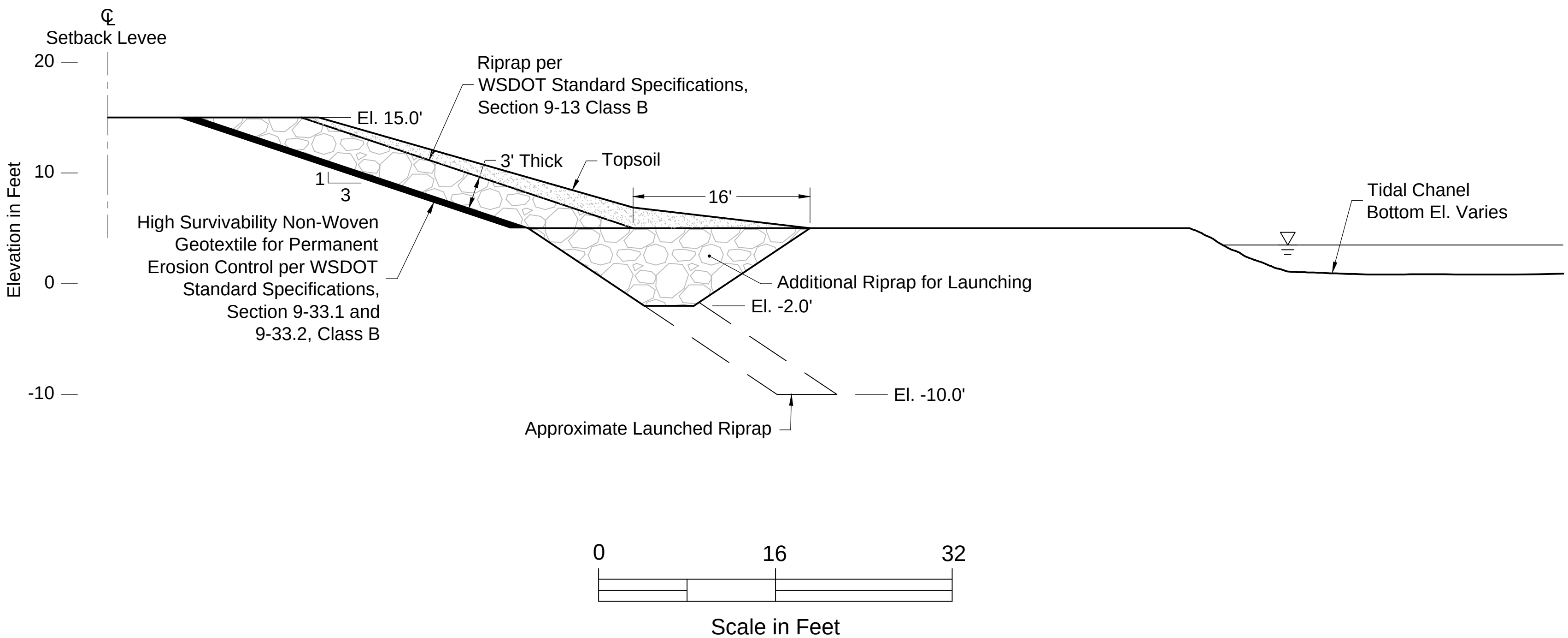
FIG. 4

FIG. 4



Smith Island Estuary Restoration Project
Snohomish County, Washington

TYPICAL LEVEE SECTION
ZONES A AND B

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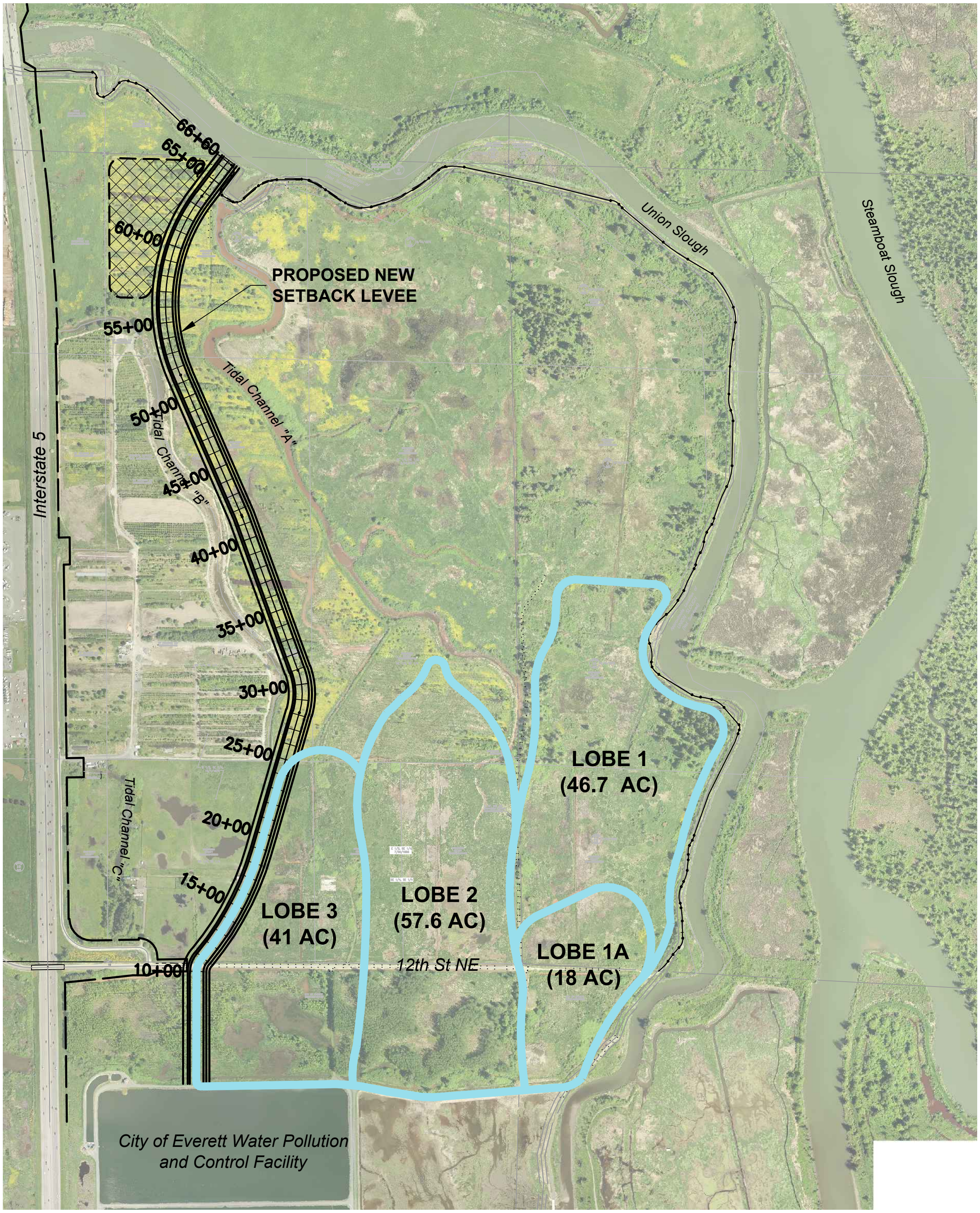
FIG. 5

FIG. 5



0 1000 2000

Scale in Feet

NOTE

Figure adapted from electronic files provided by Otak.

Smith Island Estuary Restoration Project
Snohomish County, Washington

DRAINAGE LOBES

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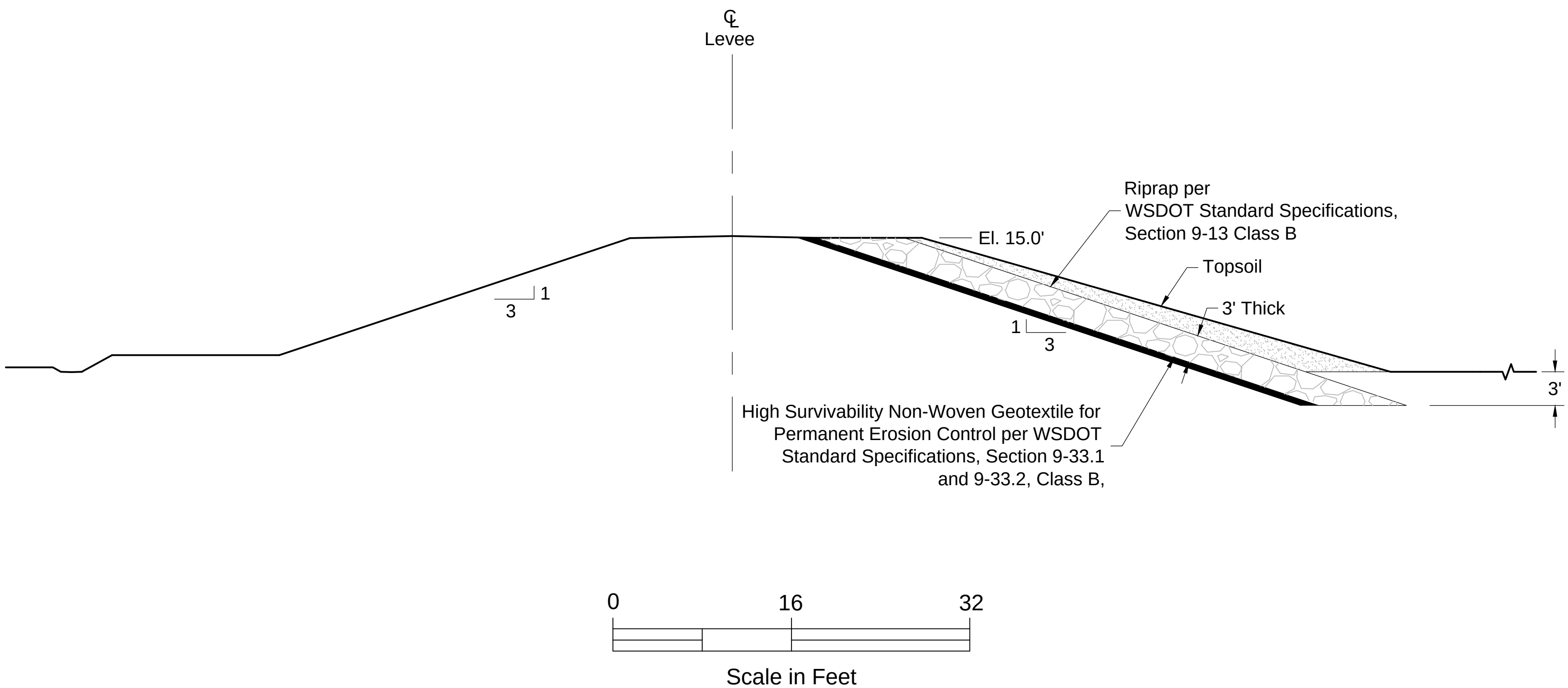
FIG. 6

Filename: I:\WIP\21-1\12405 Smith Island (Snohomish Cty)\CAD_FIGURES\-060\21-1-12405-060 Plans (Erosion Protection).dwg Date: 11-27-2013 Login: SAC



Smith Island Estuary Restoration Project
Snohomish County, Washington

TYPICAL LEVEE SECTION
ZONE C

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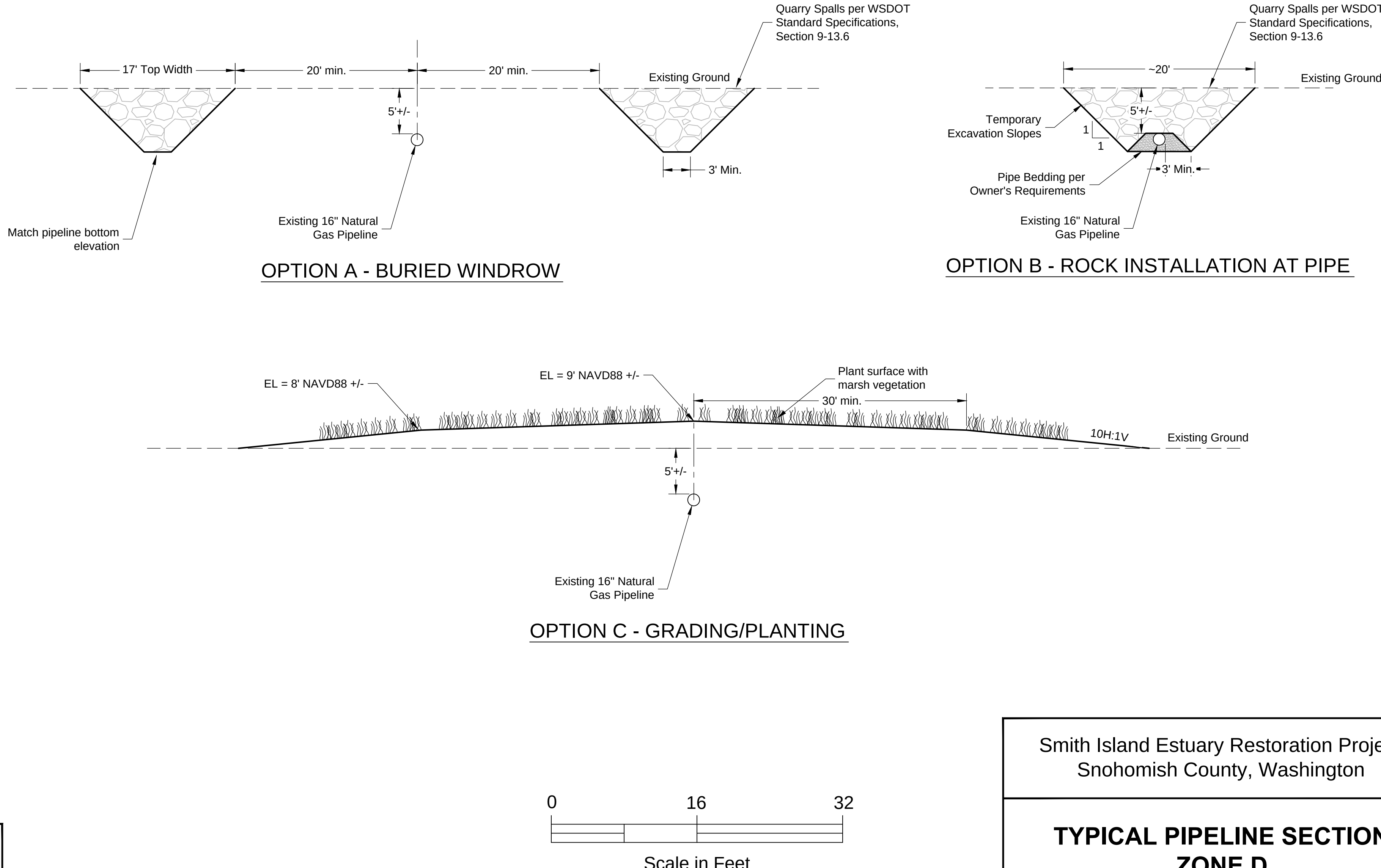
FIG. 7

FIG. 7



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TYPICAL PIPELINE SECTION ZONE D

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FIG. 8

FIG. 8